InterCriteria Decision Making Approach for Iron Powder Briquetting

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Abstract: In this paper, we present approach, called 'InterCriteria Decision Making' that utilizes the apparatus of index matrices and intuitionistic fuzzy sets which from an existing multiobject multicriteria evaluation table generates a new table that contains estimations of the pairwise relations among the set of evaluating criteria. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of iron powder. In this study we illustrate the application of the one original methodology to the data achieved for the following parameters - distance, speed and acceleration of the impacting bodies. The research and the obtained results will show relations between the briquetting process parameters which will lead to increase in its efficiency.

1 INTRODUCTION

Producing briquettes using metal chips and powder is an actual scientific problem which is reflected in a lot off publications. This technology recently is being applied more widely as per (Penchev, 2014; Radeva et al., 2014; Gustavson at al., 2014; Doremus at al., 2010; Scoglund, 2001). The positive results related to the density increasing with the impact power increases are a reason for investigating the effect using iron powder. In paper (Gustavson at al., 2014) it is shown that when compacting iron powder with impact speed 15 [m/s] a cylindrical sample of size height H = 20 [mm], diameter D = 25 [mm] and density ρ = 7.4 [gr/cm^3] has been produced. At the same time the monolith material has a density ρ = 7.5 [gr/cm^3]. This is mainly influenced by the high impact energy determined by the higher speed.

In this study we illustrate the application of the one original methodology to the data achieved for the following parameters - distance, speed and acceleration of the impacting bodies. These are analyzed by means of high speed camera and the applicable software. The impact energy (E_y) and power (F_y) are calculated. To get more experimental data an Xray tomograph Nikon XTH 225 Compact Industrial CT Scanner has been used. They are part of the equipment of the Smart Lab at IICT.

In process of the metal chips briquetting, mechanical and hydraulic presses with nominal force of several hundred to several thousand kN are used. The goal is to obtain briquettes with good density - the ratio H/D for different materials vary within wide limits (H/D = 0.8 – 0.25), where H is the height, and D is the diameter of the briquette. The greater is the density of the briquettes, the smaller are the losses in the transport and melting. Basic data used to evaluate the effect of briquetting operation is the specific density of the briquette (ρ, [g/cm^3]), and specific contact pressure for briquetting (P, [MPa]).

In the presented paper we have analyzed experimental results of iron powder briquetting. The experiments are conducted using a complicated (combined) impacting device, shown on Figure 1.

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Main element of this device is a cold rocket engine 12, working on pressurized air with pressure up to 33 [MPa]. The usage of such an engine allows for a combined impact with power F_y and additional power R.

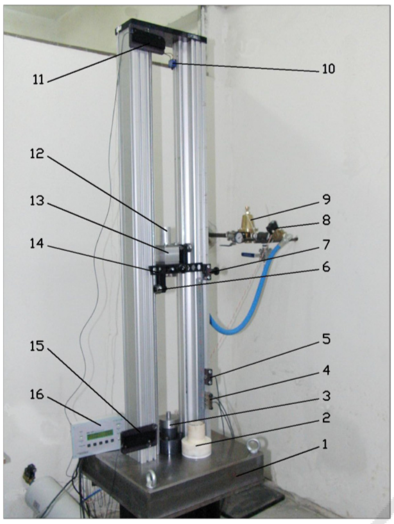

Figure 1: Laboratory stend for a complicated impact investigation:
1 – main plate weight of 220 [kg]; 2 – plastic element for elastic impact investigation; 3 – plastic impact sensor; 4 – inductive speed sensors; 5 – lower position inductive air on/off sensor; 6 – falling part rails; 7 – trigger; 8 – solenoid valve; 9 – air pressure controller; 10 – upper position inductive air on/off sensor; 11, 15 – light sensor and source for the falling part speed measurement; 12 – cold rocket engine; 13 – falling part with weight of 6.17 [kg]; 14 – plate for sensors 4, 5, 11; 16 – control panel.

To conduct the iron powder briquetting experiments we use the same stand and equipment as we did for the iron chips. The size of the particles of the iron powder we used (brand AS29-100) is determined using Fritch Analysette 22 Nano Tec+.

After high speed filming of the impact the material is processed using Vicasso 2009 product and as a result we have diagrams of the distance, speed and acceleration. Based on that we determine the impact speed V_y and acceleration A_y. Then the impact energy and power are being calculated using this data.

2 INTERCRITERIA DECISION MAKING APPROACH

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets defined by Atanassov (Atanassov, 1983; Atanassov, 1986; Atanassov, 1999; Atanassov, 2012) represent an extension of the concept of fuzzy sets, as defined by Zadeh (Zadeh, 1965), exhibiting function $\mu_A(x)$ defining the membership of an element x to the set A, evaluated in the [0; 1] - interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element x to the set A, where:

$$0 \le \mu_A(x) \le 1,$$

$$0 \le \nu_A(x) \le 1,$$

$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

The IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}.$$

Comparison between elements of any two IFSs, say A and B, involves pairwise comparisons between their respective elements' degrees of membership and non-membership to both sets.

The second concept on which the proposed method relies is the concept of index matrix, a matrix which features two index sets. The theory behind the index matrices is described in (Atanassov, 1991). Here we will start with the index matrix M with index sets with m rows $\{C_1,\ldots,C_m\}$ and n columns $\{O_1,\ldots,O_n\}$:

$$M = \begin{array}{c|ccccccc}
 & O_1 & \ldots & O_k & \ldots & O_l & \ldots & O_n \\
\hline
C_1 & a_{C_1,O_1} & \ldots & a_{C_1,O_k} & \ldots & a_{C_1,O_l} & \ldots & a_{C_1,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_i & a_{C_i,O_1} & \ldots & a_{C_i,O_k} & \ldots & a_{C_i,O_l} & \ldots & a_{C_i,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_j & a_{C_j,O_1} & \ldots & a_{C_j,O_k} & \ldots & a_{C_j,O_l} & \ldots & a_{C_j,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_m & a_{C_m,O_1} & \ldots & a_{C_m,O_j} & \ldots & a_{C_m,O_l} & \ldots & a_{C_m,O_n}
\end{array},$$

where for every p, q ($1 \le p \le m$, $1 \le q \le n$), C_p is a criterion (in our case, one of the twelve pillars), O_q in an evaluated object, $a_{C_pO_q}$ is the evaluation of the q-th object against the p-th criterion, and it is defined as a real number or another object that is comparable according to relation R with all the rest elements of the index matrix M, so that for each i, j, k it holds the relation $R(a_{C_kO_i}, a_{C_kO_j})$. The relation R has dual relation $\overline{R}$, which is true in the cases when relation R is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation R holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and $R(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and its dual $\overline{R}(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2}.$$

For every k, l, such that $1 \le k \le l \le m$, and for $n \ge 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)}, \quad \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}.$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria C_k and C_l. In this way the index matrix M that relates evaluated objects with evaluating criteria can be transformed to another index matrix M^* that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of μ and ν. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'.

Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \le 1$. We call that criteria C_k and C_l are in:

- (α, β) - positive consonance, if $\mu_{C_k,C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- (α, β) - negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- (α, β) - dissonance, otherwise.

Obviously, the larger α and/or the smaller β, the less number of criteria may be simultaneously connected with the relation of (α, β) - positive consonance. For practical purposes, it carries the most information when either the positive or the negative consonance is as large as possible, while the cases of dissonance are less informative and can be skipped.

3 EXPERIMENTAL RESULTS

In the presented paper for the analysis purposes we have used experimental results of impact briquetting of iron powder. Figure 2 shows the distance, speed and acceleration diagrams when briquetting iron powder.

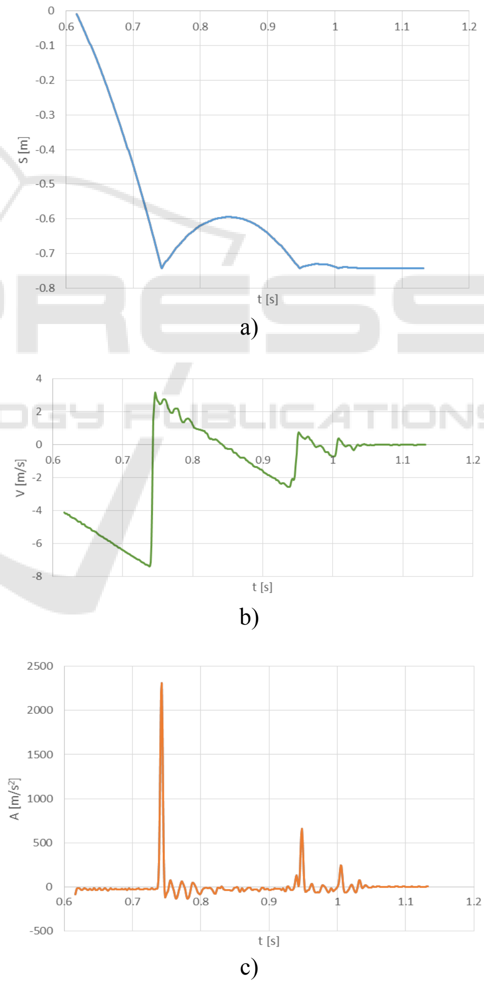

Figure 2: Distance (a), speed (b) and acceleration (c) diagrams when briquetting iron powder.

Figure 2 shows also that the acceleration and hence the force when briquetting iron powder is 38.4% higher compared to the corresponding values when briquetting iron chips.

Our experiments show that in order to improve the capabilities of this deformation process, additional investigations are required. We also prove that to have a better density in detail's walls, where we have big tension powers, a lubricant has to be added.

The analysis shows that for specific energy E_c=488 [J/cm^3] and impact speed V_y=7.37 [m/s] a cylindrical compacted iron powder sample has been produced, having density of ρ=6.7582 [gr/cm^3]. These impact process parameters can be assumed the best ones achieved for rocket engine thrust of R=226 [kN].

Based on the experimental research the values of eleven parameters of the iron powder briquetting process have been obtained:

1 - V_y – Impact speed, [m/s];
2 - A_y – Impact acceleration, [m/s^2];
3 - H_Δ – Trimming height, [mm];
4 - H – Briquette height, [cm];
5 - D – Briquette diameter, [cm];
6 - V – Briquette volume, [cm^3];
7 - G – Briquette weight, [gr];
8 - ρ – Briquette density, [gr/cm^3];
9 - E_y – Impact energy, [J];
10 - E_c – Impact specific energy, [J/cm^3];
11 - F_y – Power of impact, [N].

Table 1: Membership pairs of the intuitionistic fuzzy InterCriteria correlations for the iron powder briquette.

μ	1	2	3	4	5	6	7	8	9	10	11
1	1.000	0.528	0.389	0.417	0.333	0.417	0.611	0.611	1.000	0.611	0.528
2	0.528	1.000	0.694	0.167	0.250	0.167	0.306	0.639	0.528	0.861	1.000
3	0.389	0.694	1.000	0.361	0.278	0.361	0.167	0.333	0.389	0.611	0.694
4	0.417	0.167	0.361	1.000	0.722	1.000	0.694	0.306	0.417	0.028	0.167
5	0.333	0.250	0.278	0.722	1.000	0.722	0.722	0.500	0.333	0.278	0.250
6	0.417	0.167	0.361	1.000	0.722	1.000	0.694	0.306	0.417	0.028	0.167
7	0.611	0.306	0.167	0.694	0.722	0.694	1.000	0.611	0.611	0.333	0.306
8	0.611	0.639	0.333	0.306	0.500	0.306	0.611	1.000	0.611	0.722	0.639
9	1.000	0.528	0.389	0.417	0.333	0.417	0.611	0.611	1.000	0.611	0.528
10	0.611	0.861	0.611	0.028	0.278	0.028	0.333	0.722	0.611	1.000	0.861
11	0.528	1.000	0.694	0.167	0.250	0.167	0.306	0.639	0.528	0.861	1.000

These have been analysed applying InterCriteria decision making approach. The results are presented in Table 1.

The results show a strong relation between the parameter pairs: 1 ('Impact speed') – 9 ('Impact energy'); 2 ('Impact acceleration') – 11 ('Power of impact'); 4 ('Briquette height') – 6 ('Briquette volume'); 2 ('Impact acceleration') – 10 ('Impact specific energy'); 10 ('Impact specific energy') – 11 ('Power of impact'); 5 ('Briquette diameter') – 6 ('Briquette volume'); 5 ('Briquette diameter') – 7 ('Briquette weight').

Part of these relations is due to the specific physical properties of the briquettes, which confirms the reliability of the proposed InterCriteria decision making approach. The benefit here is that this allows for finding strong dependencies as well as such where the relations are not so visible.

The graphical interpretation results with the intuitionistic fuzzy pairs of InterCriteria consonances is shown on Figure 3.

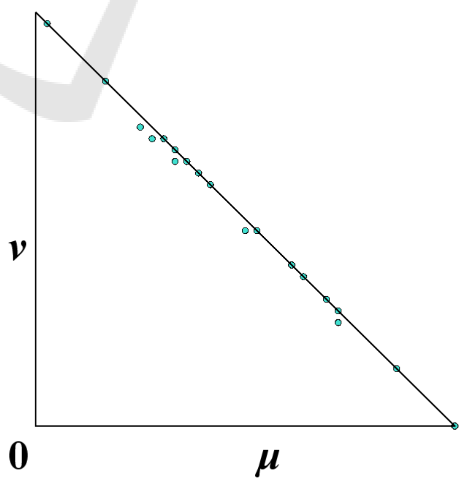

Figure 3: Geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle.

4 CONCLUSION

The research conducted shows that when producing rectangular form briquettes presence of air is observed in the final product. This is due to not absolutely complete filling of the peripheral part of the briquette. As a result the briquettes are of low density and decreased quality. To increase the product quality it is proposed elements with smaller size to be used. A possible solution is using iron powder.

The present paper proves the application of this original InterCriteria decision making approach, which eases the analysis if the relations between the criteria, giving better production quality.

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